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THESIS

ANALYSIS OF THE APPLICATION OF MODELING AND SIMULATION WITHIN THE ARMY OPERATIONAL TEST AND EVALUATION PROCESS IN SUPPORT OF WEAPON SYSTEMS ACQUISITION

by

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ANALYSIS OF THE APPLICATION OF MODELING AND SIMULATION WITHIN THE ARMY OPERATIONAL TEST AND EVALUATION PROCESS IN SUPPORT OF WEAPON SYSTEMS ACQUISITION

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ABSTRACT

The purpose of this thesis is to analyze the application of Modeling and Simulation (M&S) within the Army Operational Test and Evaluation (OT&E) process in support of weapon systems acquisition. This thesis considers the Army's current acquisition process, M&S technologies, infrastructure, and policies that guide the Program Manager (PM) in the application of modeling and simulation in operational testing. An analysis of the potential strengths and weaknesses of M&S in addressing OT&E issues is presented. Lessons learned from past OT&E efforts are analyzed for process improvement through M&S applications. The analysis indicates that M&S is a viable tool for assisting the PM in completing OT&E. M&S techniques can assist in test design validation, expand testing in areas of limited resources and environmental concerns, and validate live testing data. From this analysis, a set of recommendations are formulated, indicating where the PM can integrate M&S into the OT&E process.

TABLE OF CONTENTS

I. INTRODUCTION

A. PURPOSE

The purpose of this thesis is to analyze the application of Modeling and Simulation (M&S) within the Army Operational Test and Evaluation (OT&E) process in support of weapon systems acquisition. The focus is to provide Program Managers (PMs) a viable tool in managing the Army OT&E process. From this analysis, a set of recommendations in the area of M&S integration into Army OT&E are formulated and offered. The recommendations address both the cost effectiveness and the adequacy of the application of M&S within the Army OT&E process.

B. BACKGROUND

The modern battlefield requires continuous advancement of technology in virtually all complex weapon systems. These complex systems provide accuracy, reduce manpower requirements, and create the ability to control vast numbers of tasks simultaneously. However, because of their complexity, they pose a challenge to the OT&E process due to the high cost and difficulty of testing them in an operational environment. These difficulties arise from the complex nature of weapons on the modern battlefield and the need to maintain "technologically current" weapon systems. Two examples include weapons tracking systems capable of identifying and tracking multiple targets and communications systems capable of simultaneously processing thousands of analog and digital messages.

Within the Army OT&E process of weapon systems development, M&S is an emerging technology that is available for application in the defense acquisition process. Specifically, within the Army OT&E process, this technology offers great promise to decrease the amount of time and money spent. As the defense budget continues to rapidly decline, technologies comprising revolutionary techniques in M&S are receiving increasingly wider interest and application within the Army OT&E process. The use of M&S in the Army OT&E process of weapon systems acquisition can help the PM analyze and identify potential areas of concern before significant funds are spent in live testing and advanced development. Early use of M&S in the Army OT&E process can provide unique insight into system problems. As the cost of OT&E continues to increase with the complexity of today's weapon systems, the application of M&S in the Army OT&E process becomes ever more appealing.

Counterbalancing the appeal of the relatively low cost of M&S for OT&E applications are laws, directives, regulations, and policies mandating live testing. In the test and evaluation community, there is a widely held distrust for anything that is "simulated," including simulation used in OT&E. The validity of the simulation model is a primary concern in developing viable information and reliable test data for the PM. A critical issue that must be considered in developing the use of M&S in the Army OT&E process is the suitability of the simulation model in replicating the real-world environment. Simulation applications have the potential to evaluate virtually every component of a weapon system, in all environments, providing large amounts of data to assist the PM in managing weapons system acquisition. Accredited M&S techniques, used in the Army OT&E process, have the potential to assist the PM in delivering combat-ready weapon systems at significant reductions in both cost and time to delivery.

C. THESIS OBJECTIVE

This thesis analyzes the application of M&S in the Army OT&E process in support of weapon systems acquisition. The current use of M&S in the Army's OT&E process is analyzed to identify persistent problems and issues, and assess shortcomings in its application. Analysis is offered where M&S concepts have potential application for enhancing the Army OT&E process as to the type, extent, and applicability of M&S concepts.

Analysis of the potential strengths and weaknesses of modeling and simulation in addressing the elements and issues associated with the Army OT&E process are presented. Lessons learned from past OT&E efforts are analyzed for possible process improvement through M&S integration. Supporting conclusions and recommendations based on the analysis of the thesis are presented. Areas for further research are identified to focus future study.

D. RESEARCH QUESTIONS

The primary research question for this thesis is:

1. What current role does M&S play and what future role should it play in support of the Army OT&E process?

The subsidiary research questions are:

1. How does M&S support the Army OT&E process?
2. What regulatory and policy guidelines are established for governing the use of M&S in the Army OT&E process?
3. What types of M&S are currently being used within the Army OT&E process?
4. What types of Army OT&E methods lend themselves to the use of M&S?
5. What are the key elements to consider when using M&S in the Army OT&E process?
6. What are the capabilities of M&S in relationship to the Army OT&E process?
7. What type of information can be gained from using M&S?

E. SCOPE AND LIMITATIONS

The thrust of this thesis concerns M&S applications within the Army OT&E process in support of weapon systems acquisition. The potential issues associated with the application of M&S in this thesis are limited to the OT&E process. Specifically, this thesis addresses the OT&E process rather than the Developmental Test and Evaluation (DT&E) process.

This thesis identifies potential opportunities to integrate M&S in the Army OT&E process. The development of a common foundation of knowledge that governs the Army OT&E process will establish the various applications of M&S as an integral part of OT&E. The laws, regulations, directives, and policies pertaining to Army OT&E are examined to identify where and under what circumstances M&S integration can be accomplished and where it is prohibited. Next, a basic understanding of M&S techniques and applications will establish the plausibility of using M&S in the Army OT&E process. Finally, current Army acquisition programs are analyzed to evaluate specific successes and failures when integrating M&S into the Army OT&E process.

F. RESEARCH LITERATURE AND METHODOLOGY

Research data were obtained from official Government directives and policies, journals, previous theses, United States Code, DoD and Army regulations and manuals, and personal interviews. Information on current M&S programs was obtained from Army Training and Doctrine Command (TRADOC), Analysis Centers (TRACs), the Army's Simulation, Training and Instrumentation Command (STRICOM), and the Defense Modeling and Simulation Office (DMSO). Information on the U.S. Army Operational Test and Evaluation process was obtained from the Operational Test and Evaluation Command (OPTEC) and the Test and Experimentation

Command (TEXCOM). Current directives and policies guiding the Army OT&E process were reviewed. A comprehensive literature search was conducted to determine the existence and validity of available simulation models and techniques.

Research was conducted via personal and telephone interviews with cognizant M&S and Test and Evaluation (T&E) personnel. Interviews with OT&E related individuals concentrated on the opportunities for M&S to enhance the OT&E process. Interviews with M&S-related individuals focused on the state-of-the-art in M&S and its applicability to the Army OT&E process.

G. ACRONYMS

An extensive listing of acronyms associated with both OT&E and M&S subjects is presented in the Appendix.

H. ORGANIZATION OF THESIS

Chapter I contains the purpose, background, thesis objective, research questions, scope and limitations, methodology, and thesis organization.

Chapter II of this thesis addresses the acquisition process and how the Army OT&E process supports new weapon systems acquisition. It explores the relationship between the Army DT&E process and OT&E process, establishing the interface between M&S and the Army OT&E process.

Chapter III explores the basics of M&S as a tool for assisting the PM. It establishes a baseline of information about M&S including key elements in simulation, types of simulation available, capabilities of simulation, and types of information which simulation provides the PM.

Chapter IV outlines the Army's current guidelines and policies that affect the use of M&S in the Army OT&E process. It then compares and contrasts Army directives with those established by DoD. Current facilities that support M&S are investigated to assist the PM in using simulation in the Army OT&E process.

Chapters V and VI contain analysis of M&S applications in actual weapon systems and provides recommendations for future applications of M&S in the Army OT&E process. Areas for further research are also identified.

II. THE ACQUISITION PROCESS AND OT&E

A. GENERAL

The United States and the Army are facing a dynamic international environment which involves a complex array of security issues, unpredictable threats and a fiscally restrained domestic budget. In this environment, the Army needs to draw on its defense acquisition professionals to help overcome formidable challenges of rapidly fielding technically superior battlefield weapon systems. In an address to the National Contract Management Association in 1993, Dr. William J. Perry, as Deputy Secretary of Defense, explained the importance of fielding technologically superior weapon systems. He stated, "The advantage we had in Desert Storm had three components. We had an advantage in people, an advantage in readiness, and an advantage in technology." (Piplani, 1994, p. v) The technological advantage achieved by the military is maintained through the acquisition process. The acquisition process is the primary means through which the Army procures new equipment and technology to maintain the "technology advantage."

Operational Test and Evaluation (OT&E) is a critical component of the acquisition process that ensures weapon systems are fielded in a combat-ready status. As part of the acquisition process, OT&E is designed to assess a system's operational effectiveness and suitability in a realistic operational environment. The most capable system is useless if it cannot be employed by the intended user within doctrinal, tactical, force structure, and training requirements.

Modeling and Simulation (M&S) offers a new technology that will streamline the time and funding spent in OT&E. Simulation and modeling techniques can be applied to every major Army weapon development program to reduce design and production cost, improve performance, improve diagnostics and maintenance, assist in better and faster training of personnel, and improve command and control on the battlefield. (Piplani, 1994, p. v)

The purpose of this chapter is to briefly review the Army acquisition process and delineate the role of OT&E within the acquisition process. The chapter will conclude with the integration of M&S in support of OT&E.

B. THE ACQUISITION PROCESS

The roots of the current defense systems acquisition process can be traced to the early 1950s. Over the years many reform initiatives have been implemented to make the acquisition process more efficient and effective. However, the goal of the acquisition process has remained constant throughout the years, ". . . to procure state-of-the-art technology and products, rapidly, from reliable suppliers who utilize the latest manufacturing and management techniques that satisfies a specific user's need at an affordable cost." (Piplani, 1994, p 1-4) The policy foundation for the acquisition process is found in the DoD 5000 series.

The DoD 5000.1 establishes broad policies governing the defense systems acquisition process. It states that the three decision-making support systems must interact and interface with each other in order for the process to work effectively. The three systems illustrated in Figure 1 are: 1) requirements generation, 2) acquisition management and 3) planning, programming and budgeting (PPBS). This triad of effort is supported by a structured program of checks and balances. Figure 2 depicts the milestones in the acquisition process. Within the structure of the acquisition process, test and evaluation verifies the maturity of system design and functionality of system work performed during each milestone.

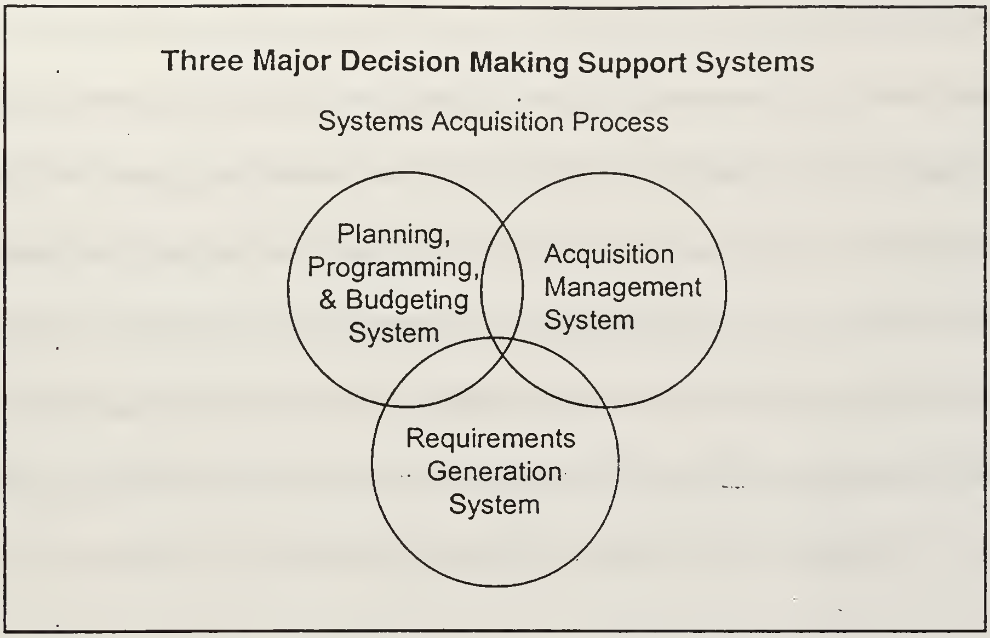

Figure 1. Three Major Decision Making Support Systems (Hoivik, 1996)

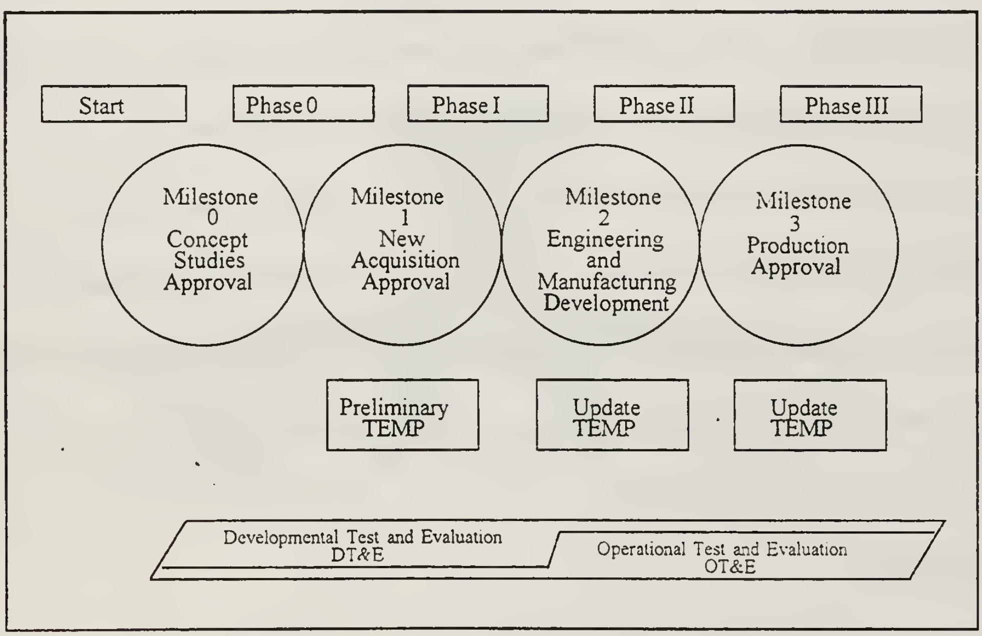

Figure 2. The Acquisition Process Milestone Support Structure (Hoivik, 1996)

C. OT&E SUPPORT OF THE ACQUISITION PROCESS

The acquisition process can take many years from the time a weapon system requirement is identified until the weapon system is fielded. As a weapon system progresses through the acquisition process, test and evaluation emphasis turns from Developmental Test and Evaluation (DT&E) toward Operational Test and Evaluation (OT&E). The fundamental purpose of OT&E in the acquisition process is to demonstrate the feasibility of the conceptual approach, reduce design risk, identify design alternatives, and estimate operational effectiveness and suitability. OT&E results weigh heavily on the decisions to continue development, to accept the system, or to change organization, doctrine, and concepts that define the weapon system requirements. (DSMC TEMG, 1988,p.1-1) Figure 2 depicts the Army T&E events in support of the acquisition process.

OT&E has an Independent Agency responsibility designed to determine if the weapon system meets user requirements. OT&E verifies the effectiveness and suitability of the weapon system. The T&E organization, depicted in Figure 3, illustrates its independent nature and authority channel. As the weapon system nears the end of the acquisition process, there is tremendous political and bureaucratic pressure to begin full-scale production. The operational testers are often viewed as "show stoppers" because successful completion of OT&E is required before any weapon system can progress beyond low rate initial production (LRIP). (LeSueur, 1994, p.12)

D. THE OT&E ROLE

OT&E programs are structured to determine the operational effectiveness and suitability of a system under realistic conditions (e.g., combat) and to decide if the minimum acceptable operational performance requirements as specified in the Operational Requirements Document (ORD) have been satisfied. (DoD 5000.2-R, 1996, p.17)

Operational performance requirements refer to the weapon system's combat effectiveness achieved when operated and maintained by typical users, within the intended doctrine and tactics, and as part of standard organizations integrated with other battlefield operating systems. Achieved operational effectiveness and suitability are distinct from weapon system capabilities (e.g., speed, range, penetration, etc.) determined during DT&E.

Realism is a critical element of the OT&E process. Realistic combat conditions are those that represent the environment, doctrine, level of training, and structure in which the evaluated system would normally be expected to operate within a combat environment.

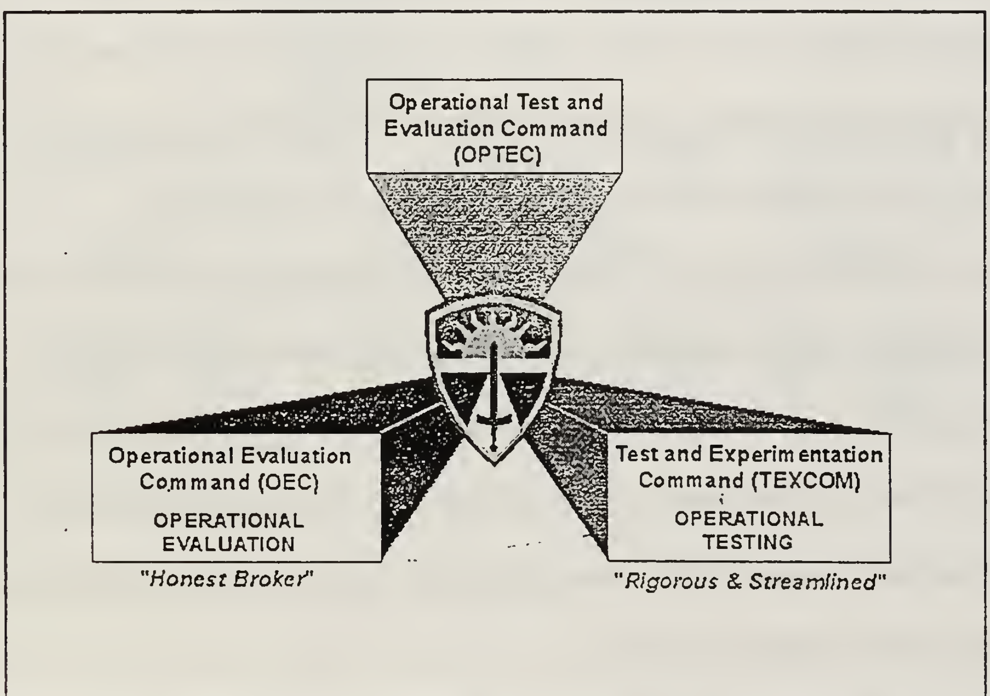

Figure 3. T&E Organization Structure (Burt, 1996)

E. THE OT&E ORGANIZATION

Congress passed legislation creating the Office of Operational Test and Evaluation in 1983 with the mission to independently evaluate the Services' weapon systems tests and assess test results. As part of that legislation, the Director of Operational Test and Evaluation (DOT&E) reports directly to the Secretary of Defense and is given broad authority to suspend major weapons programs that perform poorly in operational tests. In addition to reporting to the Secretary of Defense, the DOT&E reports directly to both the House and the Senate Armed Services Committees, at least annually, regarding OT&E of weapon systems being developed. The goal of the legislation is to save time and money by exposing problems before expensive weapons are purchased and fielded. The T&E organization is depicted in Figure 3.

The Operational Test and Evaluation Command (OPTEC) is the Army's OT&E organization and was established 15 November 1990 by Secretary of the Army General Order Number 6. The organization, depicted in Figure 4, consists of the OPTEC Headquarters and Support Agencies, the Operational Evaluation Command (OEC) and the Test and Experimentation Command (TEXCOM). OPTEC's mission is to conduct and monitor user test and evaluation (except medical) for the Army. OPTEC's test and evaluation include Initial Operational Test and Evaluation and Follow-on Operational Test and Evaluation (IOTE and FOTE) in support of the acquisition process, force development testing and experimentation (FDTE), concept evaluation program (CEP) trials, early user test and evaluation (EUTE), and the Army part of joint test and evaluation (JT&E).

OPTEC is a field operating agency of the Office of the Chief of Staff of the Army. In keeping with the Defense Directives, OPTEC reports the results of Army OT&E through the

Vice Chief of Staff of the Army directly to the Army Chief of Staff. The main part of OPTEC's mission is the planning, conducting, and reporting of Army OT&E required by law since 1972. Additionally, OPTEC conducts tests for Training and Doctrine Command (TRADOC) in support of its mission to develop combat doctrine, organizations, and material requirements.

F. OT&E IN EACH PHASE OF THE ACQUISITION PROCESS

During the Concept Exploration Phase (Phase Zero) prior to Milestone One, laboratory T&E is used to validate, demonstrate and assess the capabilities of key subsystems and components. Studies, analysis, simulation, and test data are used to explore and evaluate

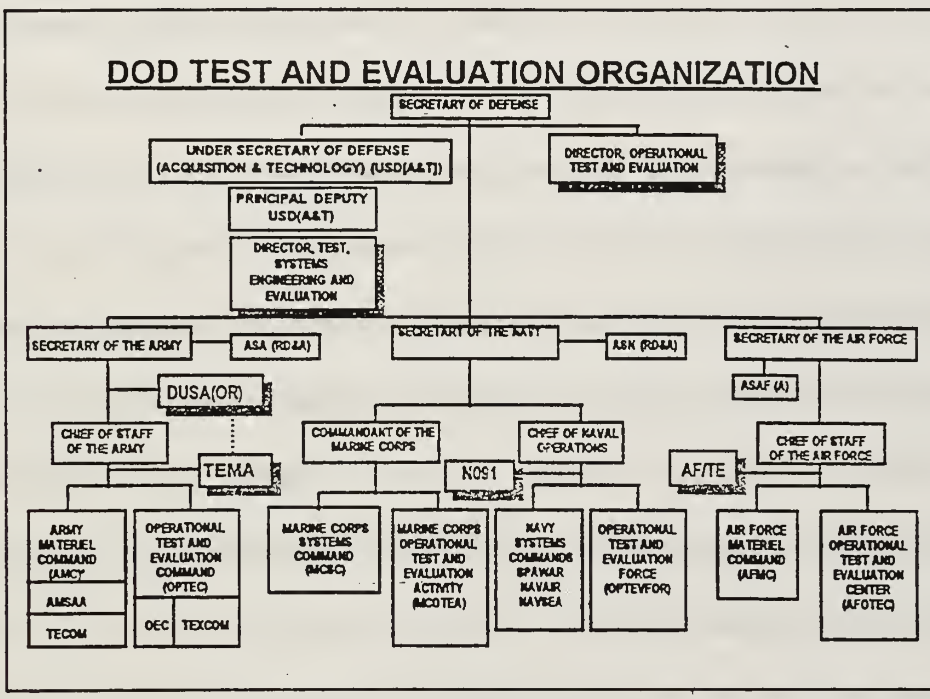

Figure 4. OPTEC Organizational Structure (OPTEC Homepage, 1996)

alternative concept designs proposed to satisfy user-generated requirements. OT&E conducted during this phase, called early operational assessment, investigates deficiencies identified during the initial mission area analysis. OPTEC monitors concept exploration for future T&E planning and provides effectiveness and suitability information needed by the program manager. Operational assessments that address the operational impact of a weapon system's technical approach are conducted.

During the Program Definition and Risk Reduction (PDRR) Phase (Phase One), operational effectiveness and suitability assessments are conducted. Information on tactics, doctrine, personnel requirements, and organizational impacts of the weapon system are gathered. OT&E assessments are used to support the Milestone II decisions for developing promising alternatives for entering Phase II, Engineering and Manufacturing Development (EMD).

The objective of the Engineering and Manufacturing Development Phase (Phase Two) is to design, fabricate, and test systems that closely approximate the final product. Prior to the Milestone III decision, a dedicated IOTE is conducted on the weapon system. This formally certifies the weapon system for "final OT&E." OT&E has the greatest impact on major programs during this phase because the decision to proceed beyond LRIP is contingent upon successfully completing the IOTE. A formal final Operational Evaluation (OPEVAL) is required prior to a Milestone III decision. The specific role of OT&E during Phase Two is to:

1. Estimate the operational effectiveness and suitability of the system.
2. Identify operational deficiencies.
3. Recommend and evaluate changes in production configurations.
4. Provide information for developing and refining logistics support requirements.
5. Estimate the survivability of the system in the operational environment.

Also, during post-production OT&E includes FOTE programs designed to verify the operational effectiveness and suitability of the production system and to determine if deficiencies identified during IOTE have been corrected. FOTEs also refine doctrine, tactics, techniques, and training programs for the life of the system. (DSMC TEMG, 1988)

G. THE CRITICAL ELEMENTS OF OT&E

The OT&E process is guided by operationally-related test and evaluation elements. These elements are unique to the OT&E process and drive the design of all OT&E programs. Because OT&E is designed to test weapon systems under "combat" conditions, these key elements are critical to effective testing. (OPTEC 73-21-1, 193)

1. Realism

Realistic environments are essential to achieving the goals of OT&E. A realistic environment is one that represents the conditions, doctrine, level of training, and structure in which the evaluated system would normally be expected to operate in a combat environment. These environments are distinctly different from those encountered in DT&E where the environment is carefully controlled.

Realism in the OT&E test process is affected by the resources available to replicate the representative threat and friendly force array, create the desired combat battlefield environment, and evaluate the system over time. Other factors affecting realism include the degree to which test participants represent typical operational personnel, test personnel familiarity with test ranges and maneuver areas, and limitations created by safety or environmental concerns.

The conditions present during OT&E must reach the limits of the evaluated system within the doctrinal envelope of operation. Stimulators, external data provided to test the system, are used to stress the limits of the evaluated system. An example of such stimulators would be the external data used to stress communications and software-intensive components of an evaluated system to levels expected in a sustained combat environment. Effective OT&E of a system also includes testing its interoperability characteristics. This includes creating a realistic structure of associated battlefield operating systems to evaluate interoperability.

2. User Orientation

An integral member of the OT&E process is the "user." Representative personnel having the correct organizational grade and Military Occupational Skill (MOS), level of training, experience, and aptitude are required for an unbiased operational evaluation of the system. "Users" include personnel that operate, maintain, support, or provide command and control functions affecting the evaluated system. The term “user" specifically excludes contractor and other personnel who would not normally be involved in the operation, control, or maintenance of the evaluated system. To avoid bias, it is important that the personnel selected to represent the user are indeed representative.

3. Representative Systems

The evaluated system equipment must be sufficiently mature to be considered functionally representative of the versions eventually fielded. Software must be complete and as near to the fielded version as possible when OT&E is conducted. All associated equipment, publications, training programs, and Test Measurement Diagnostic Equipment (TMDE) should be complete before the evaluation. The evaluated system is usually part of a larger table of organization and equipment and interacts or is supported by other standard systems. These systems must also be representative of those found in an operational environment.

4. Sufficiency

Sufficiency in the OT&E process ensures that the test plan addresses all of the issues specified in the Operational Requirements Document (ORD). The data collection plan establishes the means for collecting sufficient data and the evaluation of the collected data. The structure and use of OT&E methods for acquiring usable information are critical for a complete and unbiased evaluation.

The test plan is the key document in determining what data and under what circumstances data are collected. The test plan is driven by the user provided issues specified in the ORD. These user issues, termed Critical Operational Issues (COI), drive the test plan to ensure all requirements for evaluation are covered in testing. Sufficient, unbiased iterations of test events must be accumulated to facilitate the evaluation techniques prescribed in the evaluation plan.

H. OT&E AND M&S INTEGRATION

Modeling and Simulation (M&S) in support of OT&E is an emerging application field. M&S supports the OT&E process of weapon systems development as they proceed through the acquisition life cycle. Figure 5 depicts M&S application within the acquisition life cycle. Currently, the Army uses a wide range of M&S methods in the OT&E process. These include engineering models, battlefield environment models, and combat models. M&S can assist program managers by reducing OT&E testing costs. Areas for particular savings include: test scenario development, operational analysis of weapon systems, sequencing of test events, refinement of testing objectives, and development of measures of effectiveness. Additionally, M&S can include identifying parameters and drivers for field tests. M&S can assist in determining high risk areas, predicting test results, and assisting in testing due to safety and environmental constraints.

The primary goal of OT&E is operational evaluation. Many OT&E methods, including live and simulated testing, are used to reach that goal. M&S can replicate each of the four critical elements of OT&E, supporting complete operational evaluation. Because live testing carries a significant cost burden, many opportunities are lost to gather valuable data of some weapon systems over the life cycle. In many weapon systems, repetitive testing is critical in gaining the information needed to completely evaluate the system. M&S provides the ability to conducted repetitive testing over time at reduced cost. If OT&E were limited to live testing, it would lose much of its opportunity to contribute to decisions on whether to produce a system based on extended use. Life cycle costing is critical and without including simulation in OT&E, knowledge of the life cycle cost would be reduced. (Mann, 1983, p. 6)

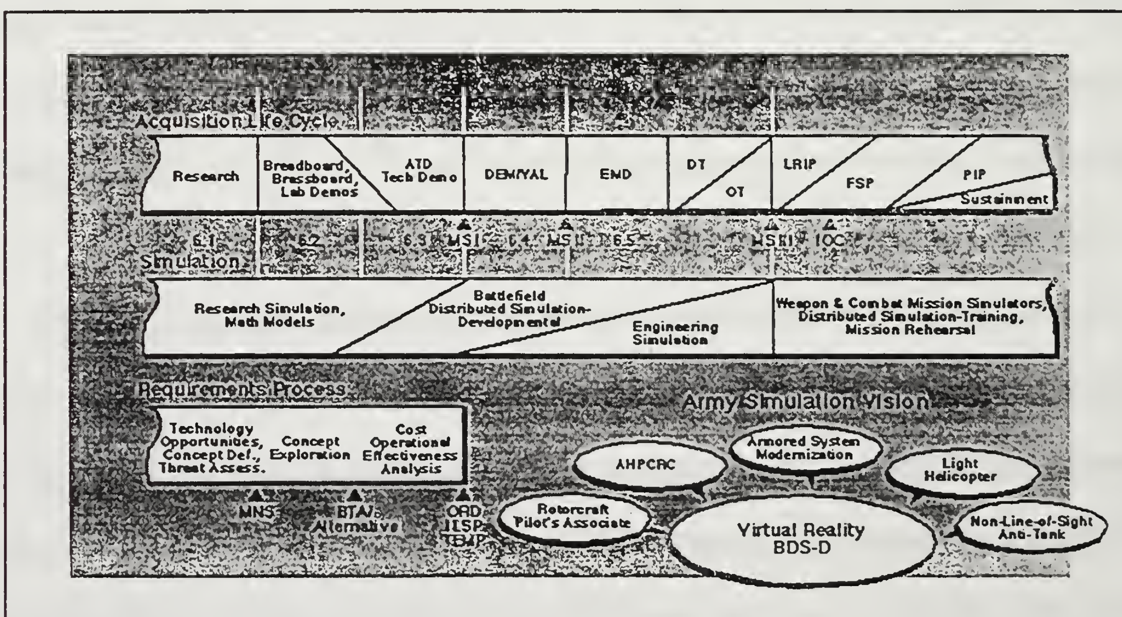

Figure 5. M&S Integration in the Acquisition Life Cycle (OPTEC Homepage, 1996)

OPTEC recognizes the use of M&S to achieve adequate realism, support economical test execution, and provide complete and adequate evaluations. However, to ensure that OPTEC maintains its objective as an independent evaluator, every M&S application used in the OT&E process must be subjected to Verification, Validation, and Accreditation (VV&A). VV&A ensues that the simulation used fulfills the four critical elements of OT&E and clearly represents a realistic operational evaluation of the weapon system. M&S applications must be accredited for each specific application. Because of the VV&A unique requirement, there is no listing or catalog of standard M&S applications available for use in the OT&E process. The VV&A conducted for one operational test does not apply to another operational test. Integration of M&S in OT&E requires advanced detailed planning that allows coordination time for VV&A. (OPTEC 73-21-1,1993)

I. SUMMARY

The U.S. and the Army are facing a dynamic international environment. The acquisition process is the primary means through which the Army procures new weapon systems and technology to maintain the "technological advantage" in this dynamic environment. The Army acquisition process is designed to field weapon systems that will provide the Army with a "technology advantage" in a dynamic warfare environment. Within the acquisition process, OT&E assesses the effectiveness and suitability of systems, concepts, doctrines, and tactics in realistic combat environments. The results of OT&E assessments have significant impact on the acquisition of major weapon systems and have visibility at the Congressional level and the top echelons of the Army. M&S techniques can be applied in OT&E to support weapon system acquisition. Utilizing M&S to assist in OT&E can aid in fighting the current and future cost constraints that negatively impact on the scope of “live” testing. Currently, M&S takes many forms that can span the acquisition process to support the PM in controlling cost, schedule, and performance.

III. ARMY MODELING AND SIMULATION

A. GENERAL

The highest echelons of Army leadership recognize the need to use advanced Modeling and Simulation (M&S) capabilities for weapon systems acquisition in the post-cold war era. In the United States Army Posture Statement FY95, The Honorable Togo D. West, Jr., Secretary of the Army stated: "The Army will maintain technological superiority through pursuit of promising advanced technologies and concepts, developing new systems when existing systems have reached the end of their useful lives or when a new system offers a revolutionary combat capability. We will exploit ... simulation to support acquisition testing, which will reduce acquisition costs." (West, 1994, p.87) Currently, the Army is using over 500 models and simulations in the acquisition process to support OT&E. (STRICOM Homepage, January 1997)

This chapter describes M&S concepts and their application in OT&E. M&S concepts will be explained in terms of classes, hierarchies, and hybrid applications. These chosen M&S applications are not all-inclusive, but are representative of the technology available. The M&S concepts and applications discussed are currently available or are being planned for use by the U.S. Army.

B. CLASSIFICATION OF MODELS AND SIMULATION

In 1992, the Defense Science Board approved the classification of models and simulations depicted in Figure 6. This classification is useful in applying M&S to Army OT&E because it allows a simple break-down of complex technologies. M&S applications range from simple models, using only one class of M&S, to complex models that integrate all three classes of simulation: constructive, virtual, and live. (DSB, 1993)

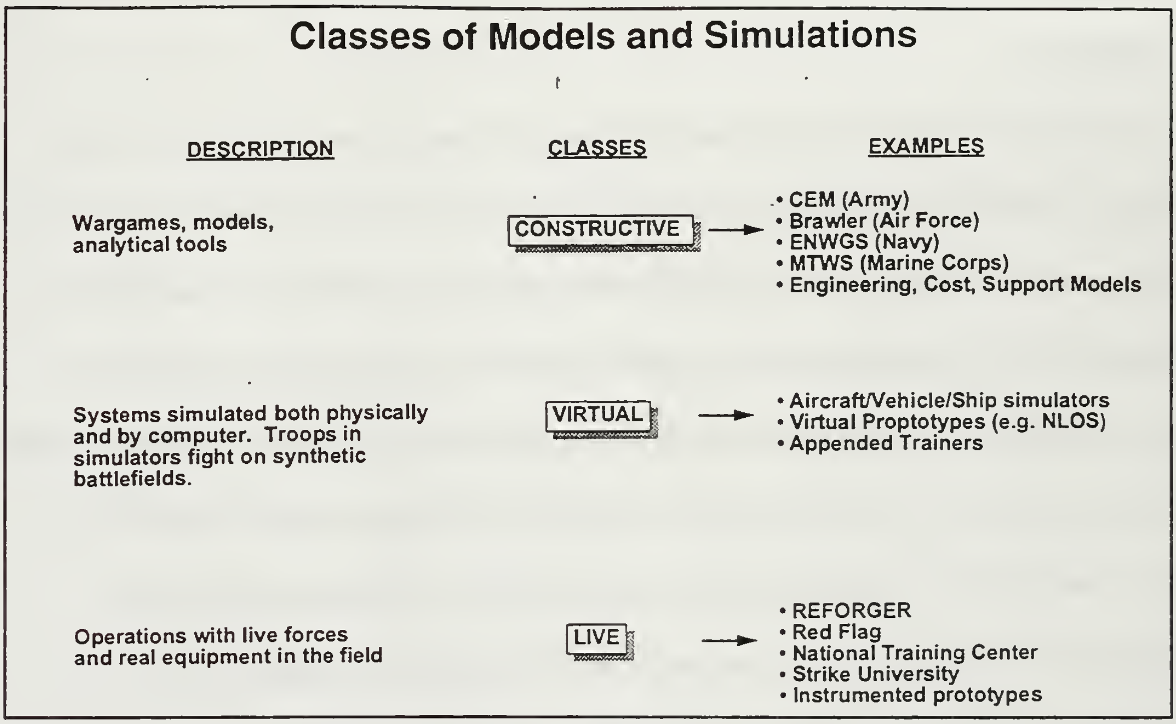

Figure 6. Classes of Models and Simulations (DSB, 1993)

1. Constructive Models and Simulations

The models and simulations contained within the constructive class currently represent the predominant form of M&S used in support of the acquisition process. Within the acquisition process, the uses of constructive M&S include design and engineering trade-offs, cost, supportability, operational and technical requirements definition, and operational effectiveness assessments. Constructive M&S consists of computer models, computer war games, and computerized analytical tools which are used by decision makers to evaluate technical specifications and to identify weapon system shortfalls. Constructive models are used to represent a system and its employment at different levels of detail. At the lowest levels, constructive M&S are used in engineering design testing, costing, and system performance calculations. At the highest level, constructive M&S provides information to identify mission short falls and to support operational effectiveness testing. (Piplani, 1994, p. 4-2)

Constructive M&S operates either with or without human interaction. Without human interaction, they may be run in multiple iterations to provide higher statistical confidence in testing. With human interaction, they validate weapon system operational tests within specification and design requirements.

2. Virtual Simulation

Virtual simulation brings the weapon system and its operator together in a synthetic or simulated environment. Synonyms are often used in describing virtual simulation, which include the terms human-in-the-loop, man-in-the-loop, warfighter-in-the-loop, or person-in-the-loop. Virtual simulations run in real time, enhancing the data gained from each test iteration. The comparatively lower cost of virtual simulation makes it an attractive testing method for the program manager. As an example, a virtual weapon system simulator may provide a virtual, but nearly-real, crew compartment with the necessary equipment, controls and display panels. A computer-generated synthetic environment is then displayed on a screen in front of the crew and on the crew compartment instrumentation. Motion of the platform is created by computer simulation to replicate the weapon system dynamics. Sounds of the system and equipment can also be duplicated. The operators are thereby immersed in an environment created by simulation that to the user (or tester) looks, feels, and behaves like the real weapon system. When using this type of M&S in testing, the tester operates the equipment, receives commands, and controls the weapons just as in actual combat. (Piplani, 1994, p. 4-3)

Virtual simulations provide better understanding of human reactions, decision processes, and man-machine interfaces. Linked to other simulators, the interaction of multiple weapon systems can be examined, leading to changes in tactics or refining weapon system designs. These simulations also provide powerful tools for testing actual system hardware and software within realistic environments for early OT&E. Additionally, virtual simulation can provide a platform for crew training prior to OT&E.

a. *Virtual Prototypes*

A more advanced type of virtual simulation is on our doorstep-- virtual prototyping. In this realm, a three-dimensional electronic virtual mockup of a weapon system allows an individual to interface with a realistic computer-simulated synthetic environment. The representation is solely a computer simulation rather than actual hardware and may be applied in early OT&E to evaluate concepts and human-machine interfaces. Additionally, it allows designers, logistics engineers, and manufacturing engineers to interface with the weapon system. Such an approach supports Integrated Product and Process Development (IPPD) and concurrent engineering, by providing a common platform from which all functional disciplines can work. The concept of the designer, operator, maintainer and manufacturer all interacting with the same realistic three-dimensional representation of the weapon system will become more prevalent in future acquisition. (Piplani, 1994, p. 4-4)

3. Live Exercises

Live exercises consist of testers and soldiers using equipment under environmental, operational, and force structure conditions that replicate actual combat. Live exercises provide a testing ground to provide "real" data on actual hardware and software operating in a near-combat environment. The introduction of multiple platforms allows for evaluation of interoperability. However, assembling the personnel and equipment to conduct a live exercise is a resource intensive enterprise requiring time, funds, and people. Data obtained during live exercises can be used to validate earlier models and simulations used in testing. This form of testing reinforces virtual simulation, ensuring the weapon system supports the mission need. Constructive and virtual simulations conducted prior to live exercises can be used to plan the tests, identify critical issues, and train the participants. Constructive and virtual simulations may also be used to analyze results after the live exercises or to augment tests that may not be feasible to conduct in live exercises due to safety or environmental reasons. (Piplani, 1994, p. 4-5)

Before proceeding further, the reader is cautioned that not every application of M&S fits neatly into one of the above classes. The lines among the various classes of M&S are becoming blurred as technology advances, allowing interoperability among the classes of M&S. Hybrid types of models and simulations are bridging the gaps among two or more classes in support of OT&E.

C. HIERARCHY OF MODELS AND SIMULATIONS

M&S supports the OT&E process across a wide span of activities ranging from design to operational effectiveness assessments. This assortment of tasks requires a suite of models and simulations with differing levels of detail, focused at particular applications. The hierarchy of M&S depicted in Figure 7 defines the differing levels of detail and their application in OT&E. Alongside the hierarchy, a force level and system work breakdown structure (WBS) are shown to indicate the system level that corresponds with the level of testing performed. (Piplani, 1994, p. 4-5)

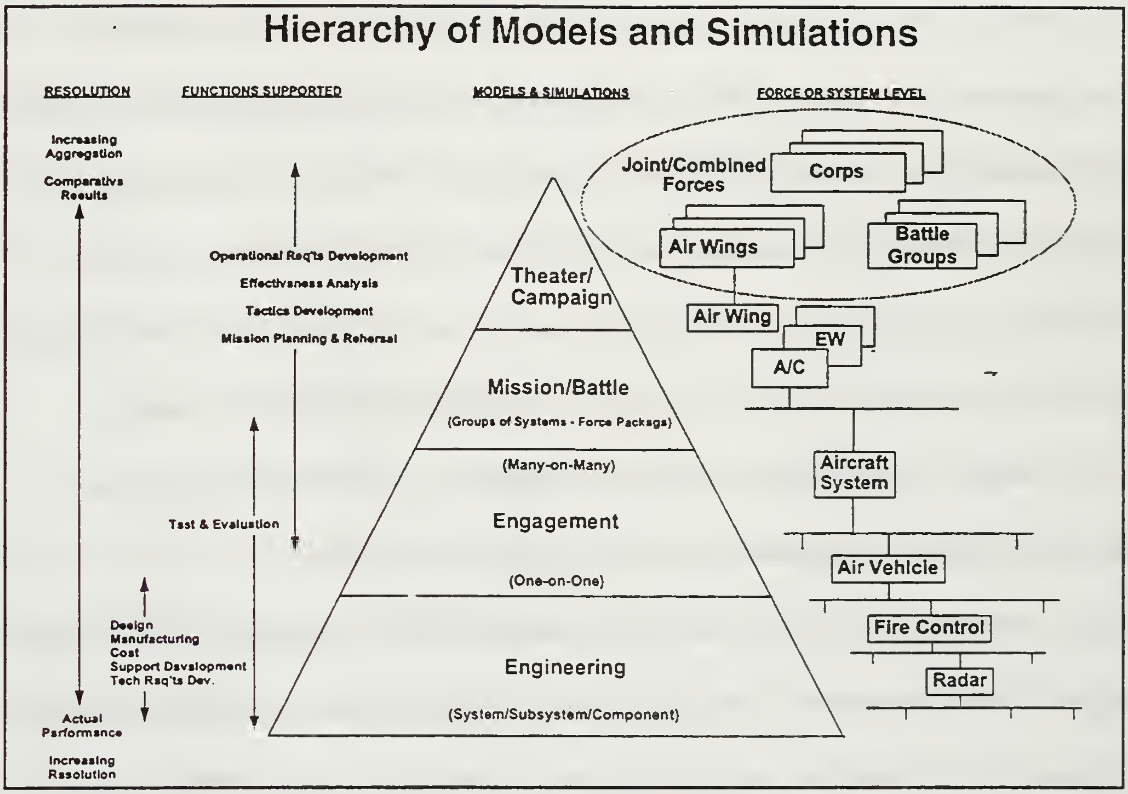

Figure 7. Hierarchy of Models and Simulations (Piplani, 1994, p. 4-6)

1. Engineering Level Models and Simulations

Engineering level models and simulations provide the basis for testing design trade-offs at the component, subsystem, and system levels. Engineering level M&S support development of technical design specifications and OT&E requirements. At the engineering level there are literally thousands of models and simulations including: (Piplani, 1994, p. 4-7)

* Basic models testing phenomenology such as aerodynamics, fluid flow, hydrodynamics, heat transfer, acoustics, fatigue.

* Physics-based models of components; subsystem; and systems for design, performance, costing, scheduling and supportability.

Examples of engineering level M&S are cost, support, and manufacturing models. Cost models generate development, production, operations, and support costs. Support models generate reliability, availability, and maintainability data. Manufacturing models generate information on producibility of a particular design, as well as simulation of maintenance work flow and requirements.

Engineering level M&S evaluate performance capabilities, often termed Measures of Performance (MOP). Examples of these measures for a missile system may include radar acquisition range, miss distance, range, payload or speed. Such performance parameters might be used in the system, development, and testing specifications. The representations of a weapon system in a higher level M&S have their basis in engineering level models. It is in higher level models and simulations that the actual impacts of weapon system performance on combat effectiveness, as part of OT&E, are evaluated.

2. Engagement Level Models and Simulations

Engagement level models and simulations represent the system in a combat scenario, such as one-on-one or many-on-many. This level of simulation evaluates the effectiveness of an individual weapon system against a specific target or enemy threat system. These models provide survivability, vulnerability, and lethality results as Measures of Effectiveness (MOEs) for the system.

The outputs from the use of engagement level M&S indicate the effectiveness of some weapon systems in an engagement scenario. Examples for a missile system may include probability of kills and/or probability of hits. The uses of engagement level M&S assist the program mangers in identifying system effectiveness and performance requirements from the Mission Need Statement (MNS) and Operational Requirements Document (ORD). Additionally, engineering level M&S is used to conduct system level performance tradeoffs and to evaluate weapon systems tactics.

D. HYBRID MODELS AND SIMULATIONS

Up to this point, the M&S classes (constructive, virtual and live) and a hierarchy of models and simulations have been illustrated. In many applications, combinations among two or more classes of M&S are used, resulting in hybrid models and simulations. A hybrid application of M&S might employ constructive models to represent a threat in conjunction with actual (live) system hardware and software. Examples of such hybrid applications include physical attributes simulation, stimulators, and hardware/software in-the-loop (HW/SWIL) simulations, and advanced distributed simulations (ADS).

1. Physical Attributes Simulation

Physical simulations refer to a physical representation of the actual operating environment (e.g., temperature, humidity, shock, vibration). Examples of physical simulation include:

* Munitions shock and vibration testing in a simulated environment.

* Survivability/ vulnerability evaluations using prototype structures and simulated environmental conditions, such as high speed airflow, temperature, and altitude.

* A firing impulse simulator (a hydraulically-operated ram) used to provide an impulse to the gun barrel to physically replicate the shock of a round being fired for durability and shock testing of the artillery piece.

* A test facility that simulates dynamic loads and motion for evaluation of tracked and wheeled vehicle suspension systems.

These are just some representative samples of physical simulations. Physical simulation can be used throughout the OT&E process at component, subsystem and system level for evaluating Critical Operational Issues (COI). The data collected from these simulations is useful for validating earlier models and simulations. (Piplani, 1994, p. 4-10)

2. Stimulation

Stimulations are “non-live” inputs given to weapon systems to test the weapon system, just as if the “real” input were present. Stimulations are used because in many instances the actual signals representing the “live” environment are not available. These include, for example, a radar’s return from a target, a signal from another weapon system, or background noise from the environment in which the weapon system must operate. Such stimulations may come from other computer models, virtual simulations or from live instrumented tests.

3. Hardware/Software-In-The-Loop

The hardware/software-in-the-loop (HW/SWIL) simulations typically span multiple classes of simulations. Figure 8 depicts HW/SWIL integration. The HW/SWIL includes actual hardware and software with M&S to demonstrate the capability of a weapon system or subsystem. An HW/SWIL simulation has proven to be an important tool in system development, test and operational support. (Piplani, 1994, p. 4-11)

In support of test programs, the HW/SWIL simulations allow for pretest simulation to identify test conditions. As a risk reduction measure, they are used for verification of actual hardware and software interaction. These simulations are also used to conduct post test analysis and to fill a test matrix for conditions that are either not testable or for which no test assets are available. The HW/SWIL simulations allow early identification and correction of developmental problems and allow one to identify and focus live tests toward critical issues. With the increasing reliance on software within weapon systems, and regular software

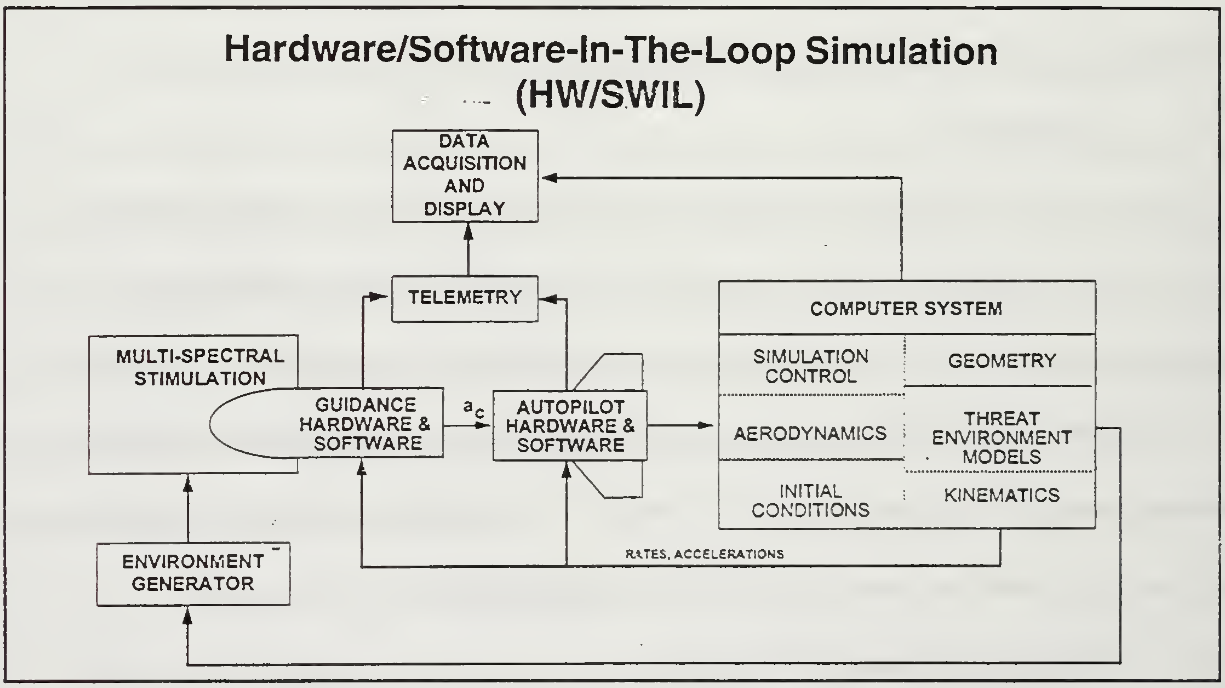

Figure 8 Hardware/Software-In-The-Loop Simulation (HW/SWIL) (Piplani, 1994, p4-11)

changes to enhance or modify performance, HW/SWIL has become a primary tool in testing the effects of software changes on performance.

4. Advanced Distributed Simulation

a. *Distributed Interactive Simulation*

One of the challenges in integrating constructive, virtual, and live simulation technologies is the use of dissimilar computer systems and simulators languages. Many models and simulations were designed independently and were not designed to communicate with one another. The integration of simulation capabilities using a common set of standard terms and protocols are needed to allow different computer systems and simulators to communicate. The standardization of terms is achieved by Distributed Interactive Simulation (DIS) Protocol Data Units (PDUs). (Crouch, 1994, p.56)

DIS creates a synthetic environment within which humans may interact through simulation at multiple, networked sites using compliant architectures, modeling, protocols, standards, and databases. DIS is the next generation of distributed simulation evolving from the Defense Advanced Research Project Agency (DARPA) research project of the 1980's known as Simulation Network (SIMNET). (IST, 1993, p.4)

DIS will take advantage of current and future simulations manufactured by different organizations. The first step in achieving this interoperability is to develop a single communications protocol. There must be a standard set of messages that communicate the states of simulated and real entities, their interactions, and among host computers. This information is communicated through DIS PDUs. The DIS is in its initial stages with many obstacles yet to overcome. (IST, 1993, p.8)

b. *Defense Simulation Internet*

DIS operations are supported by a communication system known as the Defense

Simulation Internet (DSI). This communication system was developed, and is currently operated, by the DARPA. The DSI consists of commercial telephone circuits over existing networks with nodes at user locations and strategically placed switching nodes. A central controlling facility is located in Chicago, Illinois. Connectivity is established through military and civilian communication satellites to allow worldwide, simultaneous DSI operations.

Each location connected to the DSI network is called a DSI node. There are approximately 30 DSI nodes supporting all Services' command posts, Battle Simulation Centers, test beds, Battle Labs, research centers, unified commands, and civilian contractors that support the military. The DSI is expected to expand over the next year with approximately 25 additional sites. Currently, the Army operates six core locations which make up the primary backbone of the DSI network. The Army has two TRADOC Battle Lab nodes on the DSI; Fort Knox and Fort Rucker, with Fort Rucker designated as a Battle Lab support facility. Eventually the Army wishes to operate six to eight Army Battle Lab nodes with additional communications nodes at major commands throughout the Army. (STRICOM Homepage, 15 January 1997)

Simulation tools and methodology integration between the Battle Labs and industry offer a new area of innovation that has potential to support the acquisition process. The use of concurrent engineering principles reduces development time and speeds the acquisition process. Virtual prototypes will enhance early design and manufacturing tradeoffs, leading to effective OT&E. Eventually the manufacturing process, the actual weapn system, and the system's performance may all be modeled, integrated, and tested before the first piece of hardware is built. (BLG, 1993, p.6) Synthetic environments will not completely replace hardware testing. However, given the increased costs of hardware development and testing, contrasted with the decreased costs and advancing technology simulators, synthetic environments become ever more appealing. (BLG, 1993, p.7)

E. SUMMARY

The Army is moving to take advantage of advanced M&S opportunities and the potential cost savings M&S offers in a fiscally constrained post-cold war era. As a vital part of the acquisition process, OT&E can integrate M&S concepts and applications to address recurring problems and shortcomings in cost, schedule, and OT&E performance. The classes of M&S can be included in OT&E planning to help the program manager in reaching cost, schedule, and performance goals. With the high cost of live testing, the use of less resource-intensive forms of testing, such as M&S, is a smart preparation tool. As an integral part of OT&E planning and support, M&S allows a program manager to use costly and valuable assets more efficiently.

The Army will link M&S technology components together through networks such as the Defense Systems Internet (DSI) to create environments such as the Distributed Interactive Simulation (DIS). Relying heavily upon simulation and modeling technologies, senior Army leaders will use M&S as a tool to help save money by speeding up the introduction of promising new weapon systems. The Army's leadership is setting policies that endorse M&S use in today's costly acquisition process.

IV. ARMY SIMULATION - POLICIES AND REGULATIONS

A. GENERAL

The Operational Test and Evaluation (OT&E) process is guided by numerous policies and regulations. The provisions of these mandates and guiding vehicles directly affect how OT&E for a weapon system is planned, conducted, and analyzed. The role of M&S in the OT&E process is directed by the policies and regulations guiding OT&E. Initial efforts in providing effective policy and regulatory guidance lay the foundation for refining the Army's future processes for managing its M&S investment. Policy and regulatory guidance define how OT&E can encompass M&S to streamline the OT&E process. This chapter describes the general Army policy and regulations that affect the use of M&S in OT&E.

B. ARMY AND M&S POLICIES

The Army is adopting policies to take advantage of advanced M&S opportunities. Army leaders are setting the M&S policy cornerstones as evidenced by Army Chief of Staff, General Gordon Sullivan's statement;

> You need to know that we will use simulation techniques throughout the Army's acquisition process. We will determine needs in large-scale, simulation-supported exercises that allow us to consider alternative solutions that meet our needs. We will use drawings, diagrams, and 3-dimensional models generated by computers, put them in constructive or virtual environments, and test alternatives both technically and tactically. The most promising technologies will be tested by real soldiers, first in reconfigurable crew stations, then in full scale simulations. Final designs, production and assembly steps will also be simulated in virtual factories before actual prototypes are made. Then the actual and virtual prototypes will be tested simultaneously to discover potential problems before production begins. Tactics, techniques, and procedures are also developed along with the system so that the system is fully ready for use when produced. (Sullivan, 1993)

Lieutenant General William H. Forster, the Military Deputy to the Assistant Secretary of the Army (Research, Development and Acquisition), further refined the M&S policy in his 24 May 1993 Memorandum for the Deputy Commanding General, Army Materiel Command and all Program Executive Officers. Under the subject of "Simulation Support to the Army," LTG Forster stated,

> The Army Science Board and the Defense Science Board have recently studied the potential improvements to DoD acquisition offered by advanced simulation, particularly Distributed Interactive Simulation (DIS). Both concluded that simulation can improve acquisition from concept to fielding through such innovations as: virtual prototyping; engineering simulation; linking of constructive, virtual and/or live simulations; assisting the user in execution of experiments in employment tactics; user test design and critical issue identification; and improved training prior to fielding. (Forster, 1993, p.1)

Policies integrating M&S into the acquisition process have been initiated from the top levels of the Army. Additionally, organizations have been established and charged with pursuing new technologies and investigating concepts using an integrated M&S approach. Concepts for integrating M&S into the OT&E portion of the acquisition process are coordinated through three primary organizations: The Army Model and Simulation Management Office (AMSMO), Operational Test and Evaluation Command (OPTEC), and Army Material Systems Analysis Activity (AMSAA).

The Army Model and Simulation Management Office (AMSMO) is the focal point for establishing and maintaining the methodology by which to identify and share information among agencies, organizations, and activities in the Army community who use or develop M&S. The AMSMO promulgates Army M&S policy, publishes guidance, and administers the Army Model Improvement Program (AMIP) and Simulation Technology Program (SIMTECH). Additionally, AMSMO develops and publishes the Army Modeling and Simulation Master Plan, implementing procedures such as the verification, validation and accreditation (VV&A) of Army models and simulations. (AMSMO Homepage, 1996)

The Operational Test and Evaluation Command (OPTEC) is the Army's lead agent for operational test and evaluation. OPTEC is charged with integrating M&S throughout the testing process. OPTEC's goal is to apply cost-effective techniques to situations of limited testability. Additionally, OPTEC incorporates the notion of Distributed Interactive Simulation (DIS) through the use of constructive and virtual simulations in operational testing. (OPTEC Homepage, 1996)

The Army Material Systems Analysis Activity (AMSSA) maintains configuration control on M&S for item level performance. This includes one-on-one system performance, many-on-many system combat performance, and larger war gaming simulations for OT&E. AMSSA uses M&S to provide allied and threat systems performance data for use in cost and operational effectiveness testing in Army studies and in support of the acquisition process. AMSSA assists in accreditation and provides certified systems performance data characteristics and data to the Army testing community. Additionally, AMSSA provides VV&A support to OPTEC and the Army Material Command (AMC). (AMSSA Homepage, 1996)

C. PRIMARY REGULATIONS GOVERNING M&S

Dramatic advancement in modeling and simulation have made its use in the OT&E process more attractive to many program managers. Operational testers are beginning to use M&S to support OT&E. Lawmakers are attempting to exploit the advances in M&S by adjusting or creating regulations that specify the use of M&S in OT&E. Figure 9 depicts the primary documents that govern the use of M&S in the acquisition process and OT&E. Each document provides focus to guide the potential M&S user.

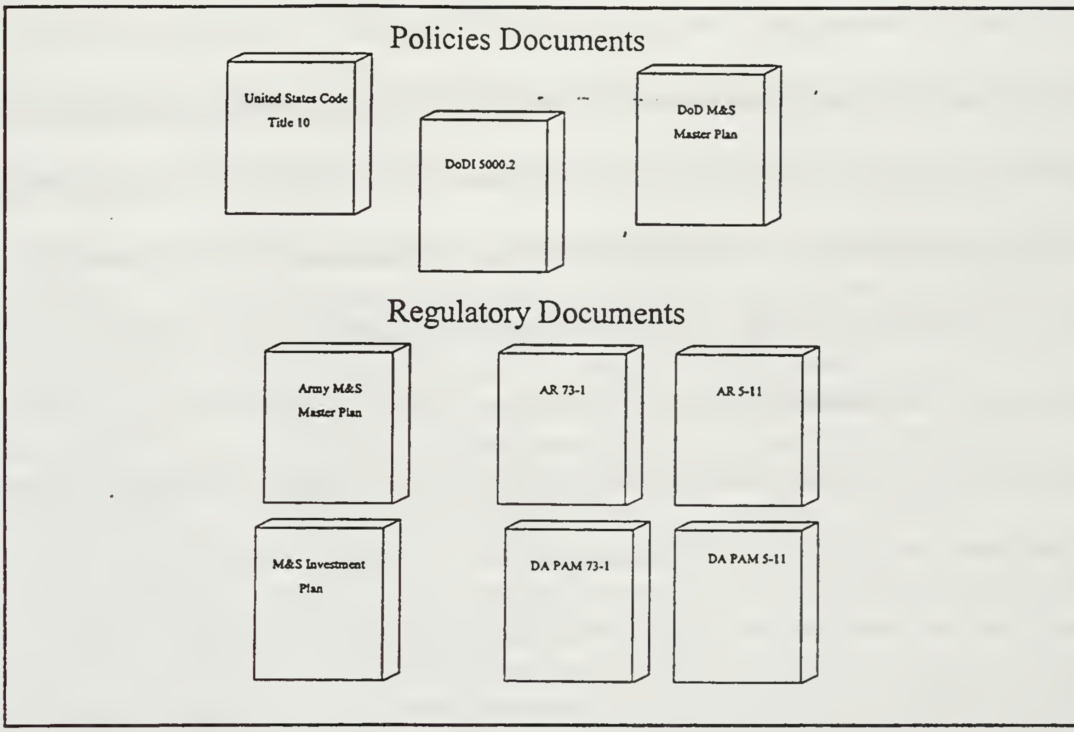

Figure 9 Documents and Regulations

1. Title 10, United States Code

United States Code, Title 10, Chapter 138 has two sections that pertain to the OT&E process. Section 2399, Operational Test and Evaluation of Defense Acquisition Programs, and section 2366, Major Systems and Munitions Programs: survivability, lethality, and operational testing.

Section 2399 establishes the conditions necessary for a major program (acquisition category I and II) to proceed beyond low rate initial production (LRIP). This provision states that a major defense acquisition program may not proceed beyond LRIP until the Initial Operational

Test and Evaluation (IOTE) for that program is complete. It further directs that the Director of Operational Test and Evaluation (DOT&E) shall analyze the results of major systems' OT&E. The resulting report shall state the DOT&E's opinion regarding OT&E adequacy and whether the results indicate that the evaluated system is effective and suitable for combat. (USC, 1989, pp.230-231)

Section 2366 directs the Secretary of Defense to ensure that no major system proceeds beyond LRIP until the IOTE survivability and lethality testing is complete. This section specifically defines the conditions required for survivability and lethality testing. These conditions include the requirement for live fire testing on representative systems and, therefore, preclude any major system from being acquired solely on the basis of OT&E conducted using only M&S. (USC, 1989, pp.581-582)

2. Department of Defense Regulation (DoD) 5000.2-R

This regulation references and reinforces the provisions of Title 10, Unites States Code. It directs that OT&E shall be designed to support the decision to proceed beyond LRIP and establishes four objectives for OT&E testing:

1. Provide essential information for assessment of acquisition risk and for decision making.
2. Verify attainment of technical performance specifications and objectives.
3. Verify that systems are operationally effective and suitable for intended use.
4. Provide essential information in support of decision making.

With regard to the use of M&S in the OT&E process, DoD 5000.2-R interprets Title 10 in a strict manner. The regulation states that OT&E does not include an operational assessment based exclusively on computer modeling and simulation. (DoD 5000.2-R, 1996, p. 15)

3. DoD M&S Master Plan

The DoD M&S Master Plan is the Department's first effort in directing, organizing, and concentrating M&S capabilities and efforts. It provides a means to achieve a common technical and policy consensus. Because of the immense breadth and scope of DoD M&S uses, combined with the relative immaturity of many segments of the larger DoD M&S community, a comprehensive and complete master plan is difficult to obtain. This plan is intended to be dynamic and flexible, a living document that will evolve as M&S technology matures and consensus develops on policy and programmatic issues. While many policy and technical issues are not identified or resolved, it does, however, provide the management framework and policy direction for further implementation of M&S in the acquisition process. Over time, with the active participation and support of the DoD M&S community, the DoD M&S Master Plan will mature to address the full range of issues confronting M&S applications within DoD.

4. Army M&S Master Plan

The Army M&S Master Plan provides information on the modeling and simulation vision, standards development process, and objectives for the Department of the Army. It represents a statement of the future use of M&S within the Army. The Army M&S Master Plan adopts the same M&S objectives as the DoD M&S Master Plan. Additionally, the Army M&S Master Plan provides guidance to program managers and operational testers on how to develop plans, programs, and projects to incorporate the objectives of the Army in relation to models and simulations.

5. Army Regulation 5-11, Army Model and Simulation Management Program

Army Regulation 5-11 (AR 5-11) describes what types of M&S fall under the purview of this military regulation, as well as those types of M&S that are excluded. Specifically, M&S used for education and training, analysis, test and evaluation (T&E), research and development (R&D), or production and logistics are to be responsive to the provisions of AR 5-11. Also included are models and simulations that produce input for other models, whose results are then used by Army decision makers. M&S developed and/or used by contractors or federally funded research and development centers (FFRDC) in support of Army activities must also comply with the provisions of AR 5-11. Finally, simulators, semi-automated forces (SAFOR), and models and simulations that operate in a Distributed Interactive Simulation (DIS) environments are likewise included in this grouping. Models and simulations not falling under the purview of AR 5-11 are system training devices, those embedded in weapons systems, machines or tools, and instrumentation that does not communicate outside the primary weapon system or device.

a. *DA PAM 5-11*

This new Department of the Army Pamphlet (DA PAM) sets procedures for policy contained in AR 5-11, the Army Model and Simulation Management Program. The objective of this pamphlet is to assist the M&S developer, proponent, and application sponsor in conforming to the verification, validation, and accreditation (VV&A) provisions prescribed in AR 5-11. This pamphlet also provides guidance for the development, execution, and reporting of all VV&A activities. This pamphlet does not cover data certification procedures, but it does address data certification in reference to proper M&S use. DA PAM 5-11 outlines all of the documentation, configuration management, certification, and verification and validation requirements of data in M&S.

6. Army Regulation 73-1, Test and Evaluation Policy

Army Regulation 73-1 (AR 73-1) directs the implementation of DoD Directive 5000.1 and DoD Regulation 5000.2-R. This regulation describes the type of OT&E application to be provided in support of each phase and milestone. It links T&E to the acquisition process and directs that T&E be designed to support the acquisition phases and milestones. Within this regulation, OPTEC is charged with the overall management of Army OT&E, including the integration of M&S where possible to reduce cost, save resources, and verify available data.

a. *DA Pamphlet 73-1*

Department of the Army Pamphlet 73-1 (DA Pam 73-1) suggests the uses of models and simulations in test and evaluation (T&E). M&S will be considered to support the developmental and operational T&E of software and weapon systems as they proceed through the acquisition life cycle. The use of M&S will include, but not be limited to, the identification of test parameters and drivers for field tests; determination of high risk areas; prediction of test results; assisting in the allocation of scarce test resources; and the assessment of system capabilities in situations that cannot be tested due to safety, cost, or other constraints. Simulators, emulators, drivers, and stimulators which are used to fully exercise weapon systems under operational test conditions are also included. DA PAM 73-1 stipulates that M&S used for T&E must be accredited and validated prior to its use for extrapolation or predicting system performance (including software, hardware, man-in-loop). The degree to which M&S will augment OT&E to assist in weapon system evaluations and assessments will be documented in the Test and Evaluation Master Plan (TEMP).

The TEMP is the principal document for test scheduling and planning for the program manager and the T&E community. TEMP planning aids decision makers by verifying that the weapons systems have attained their technical performance specifications and objectives. Specifically, the TEMP ensures that testing will meet operational effectiveness and operational suitability requirements as designed by the user. Additionally, the TEMP addresses whether existing M&S will be used or whether new M&S will be developed to support OT&E.

D. REGULATION OVERVIEW

Army M&S regulations provide the flexibility to allow each acquisition program to tailor a T&E strategy applying M&S to achieve maximum program performance. Operational test strategies must be generated concurrently with the acquisition strategy to assure that M&S is an integral part of the acquisition program. Modeling and simulation will be considered to support the technical and operational T&E of all systems (hardware and software) as they proceed through the acquisition life cycle. Models and simulations used for OT&E must be accredited and validated prior to their use for extrapolation or predicting system performance. The use of M&S, whether existing or new, will be documented in the Test and Evaluation Master Plan (TEMP)

E. SUMMARY

The continuing revolution in advanced technologies has widened the opportunity for using M&S in OT&E. This technical revolution has increased the number of users of Army M&S to the point that M&S touches almost all aspects of the acquisition process. To support the growing use of advanced technology, policy and regulations have been established to provide a common reference and standard to enhance and focus concurrent use of M&S applications. Current policy and regulations are designed to assist the program manager in using M&S applications. The development of clear policies and regulations have led to a better understanding of the Army M&S management and an increased visibility of M&S activities. As advancements in M&S technologies continue, the Army will refine current regulations and spawn new organizations that will influence policy. These new organizations will update polices and drive lawmakers to revise current regulations, encouraging the use of M&S in OT&E.

Investments in M&S provide a critical underpinning for a variety of Army missions, from designing a future force, building systems and doctrine for that force, and finally to testing weapon systems for that force. The current downsizing of the Army creates pressure to reduce costs at every level, including within the OT&E process. As the Army continues to increase the use of M&S in OT&E, it will see better resource management, cost savings, and enhanced verification of testing data. The next chapter illustrates, through case analysis, the results of the application of M&S in OT&E.

V. CASE ANALYSIS

A. GENERAL

> The OT&E community has a most difficult role in defining when, where and how it can participate outside the live environment. Operational testers find themselves caught between United States Code, Title 10 mandates and the spiral of diminishing defense dollars. This is a most dangerous position. (Crouch, 1994, p.86)

The "most dangerous position" refers to a situation where the OT&E independent evaluator (OPTEC) does not integrate M&S into the testing process but continues to use expensive live testing, while program managers (PMs), materiel, and combat developers push to incorporate cost effective and realistic M&S applications for OT&E certification. Current technological advancements in M&S provide the required simulation fidelity, making M&S a viable alternative for some early and follow-on portions of OT&E. (Crouch, 1994, p.87)

This chapter examines the application of modeling and simulation in OT&E. Specifically, three weapon systems will be used to illustrate the viable application of modeling and simulation in OT&E. The three primary weapon systems are the M1A2 Abrams Main Battle Tank, the Javelin Antitank Missile system, and the AH-64D Longbow Apache Helicopter.

B. METHODOLOGY

This analysis will focus on four major OT&E issues: test design validation, resource constraints, safety and environmental concerns, and data reliability and validity. Each of the four areas is critical to successful OT&E. These major OT&E areas of concern were established by conducting interviews with experienced OT&E professionals assigned to the TEXCOM, STRICOM, and Program Management Offices. Additional interviews were also conducted with personnel from OPTEC and TRAC Monterey. Interviews were critical in identifying the level of M&S integration for the OT&E programs of each weapon systems examined. The areas of concern were selected when at least two of the three OT&E programs experienced similar problems and issues.

1. Overview of Issues

The four OT&E areas of concern are test design validation, resource constraints, safety and environmental concerns, and data reliability and validity. The general concerns of each area and their application in this thesis are described in the following paragraphs.

a. *OT&E Test Design Validation*

Test design issues were categorized as OT&E test design validation concerns when shortcomings were associated with the baseline test design. The validation process ensures that baseline scenarios and test execution plans satisfy the user and evaluator requirements for data collection, while simultaneously meeting the mandates and guidance for the conduct of OT&E.

A desired method for test design validation is the use of a pilot test. A pilot test is a rehearsal of test events using test participants, fully instrumented candidate systems, data collection resources, test ranges, and maneuver areas. A pilot test is useful in determining if the data collected address the criterion under consideration for specific OT&E events. The pilot test advantages include validation of test scenarios, data collection plans, test facilities, and pretest training with no test report impact. Disadvantages include time and funding requirements, early user familiarization with the candidate system, test facilities, and test trial scenarios.

b. *Resource Constraints*

Shortcomings associated with time, personnel, equipment, and funding availability were categorized as resource constraints. These shortcomings impact the OT&E test design and scope in terms of realism, environmental diversity, scale of threat and friendly force structures, and number of OT&E event iterations. The degree to which resources are constrained determines the operational scope replicated in the live test, including both the type and amount of data available for evaluation.

c. *Safety and Environmental Concerns*

OT&E events that were eliminated or unrealistically controlled because of potential hazards to personnel or released pollutants into the environment were categorized as safety and environmental concerns. As the range, lethality, and destructive ability of associated systems all increase with new technologies, safety concerns often limit the use of the actual weapon system to very controlled circumstances that are not representative of a combat environment. Weapon systems that create radioactivity, release ozone depleting compounds, and other environmentally hazardous by-products are limited to controlled scenarios.

d. *Data Reliability and Validity*

Issues associated with test data interpretation or unusual test participant qualifications were categorized as data reliability and validity concerns. Live test events contain an infinite number of variables, providing an opportunity for assigning cause to undesirable outcomes, eliminating outliers, and/or biasing data. Obtaining reliable and valid data for evaluation is difficult in an uncontrolled environment. Data reliability and validity are affected by both the test design and the operational experience level of the tester. The degree to which test participants represent typical operational users impacts projected force structure and tactical unitization of the weapon system for combat operations.

2. Overview of Primary Weapon Systems

a. *M1A2 Abrams Main Battle Tank*

The M1A2 is the second major block improvement to the Abrams Main Battle tank. Enhancements to the M1A1 Abrams include the Inter Vehicular Information System (IVIS), Commander's Independent Thermal Viewer (CITV), Position/Navigation System, an Improved Commander's Weapon Station, and integration of the vehicle electronics system through the use of dual redundant data and utility bus architecture. This weapon system is designed to be fielded in armored, mechanized infantry, and cavalry units, ranging from platoon to division sized elements. (Patten, January 1997)

b. *Javelin Anti-Tank Missile System*

The Javelin (formerly known as the Advanced Antitank Weapon System-Medium) is a man-portable, fire and forget, advanced antitank missile system capable of defeating all known armor threats. The Javelin is replacing the shoulder-fired Dragon missile system and provides extended range and improved attack attitudes. It will replace most Dragon systems in combat and combat support units from platoons through corps level. (Knox, January 1997)

c. *AH-64D Longbow Apache Helicopter*

The AH-64 is the Army's premier attack aircraft, providing direct and indirect fire support to both ground and air targets. The Longbow Apache is an upgrade to the AH-64D Apache. The enhancements include improved target acquisition and firepower effectiveness, increased survivability and lethality, improved adverse weather fighting capabilities, improved armament (including Longbow Hellfire missiles), and automated systems, engines, and fire control radar. The Longbow Apache will replace attack helicopters currently fielded in attack helicopter units at battalion through corps echelons. (Wolfe, January 1997)

C. ANALYSIS OF M&S APPLICATION IN OT&E

OT&E problems and issues within each of the identified categories are detailed and the capabilities of M&S applications to resolve them are analyzed in the following paragraphs. The analysis is organized by issue category.

1. Test Design Validation

The operational test design establishes the amount of data and the circumstances in which data are collected. Test design lays the foundation for the amount of operational realism achieved. Creating realistic combat conditions in OT&E tests can be hampered by many factors: accurate interpretation of Test and Evaluation Master Plan (TEMP) critical issues, poor understanding of the environments and scenarios, and force structures required to replicate a representative combat environment. The M1A2, Javelin, and Longbow Apache test designs had shortfalls in test design validation.

a. *M1A2 Main Battle Tank*

The M1A2 live test used an operationally smaller force structure than doctrinally employed in combat operations. Operational testing of the M1A2 tank at the brigade or divisional levels was not conducted. Operational testing was limited to one battalion-sized task force. Battalions deploy, fight, and are supported differently than brigades or divisions. The reduced scale significantly increases data assessment extrapolation risks for normal combat operations.

A constructive simulation, such as Janus, appears to have application in addressing operational test design shortfalls similar to those experienced by the M1A2. Constructive simulations are useful for assessing operational environments and combat scenarios beyond the scope of limited live operational testing. Constructive simulations can replicate a wide range of force structure, environments, threat forces, and combat intensities. In using constructive simulation to address operational test design issues, live testing can be enhanced across the operational spectrum of the battlefield.

TRAC White Sands Missile Range (WSMR) used a system similar to Janus to assist in the M1A2 OT&E test design validation. Experiments were designed on a Janus based constructive simulation, and experiments were iteratively conducted for predictive analysis. Actual test articles were instrumented and data was collected on live test trials. Live test iterations were replicated on the simulations and then correlated. The correlated simulations were then used in other environments and scenarios within the M1A2 operational spectrum and analyzed. The insights gained from these simulations were used to assist in the M1A2 live test conducted at TEXCOM Experimentation Center (TEC). Live OT&E test events were selected based on the simulated event outcomes that indicated a high probability for obtaining the required data to address critical issues. (Payan, 1994)

b. *Javelin Missile*

Battlefield operating systems normally interoperating with the Javelin missile systems were not included in the Javelin test plan. Javelin is deployed in conjunction with other anti-armor systems including tanks, artillery, and close air support. An interoperational environment was too expensive and impractical to replicate in a live operational test, and was omitted from the test design.

M&S can provide a method for addressing interoperability issues such as those experienced by the Javelin during OT&E. Constructive simulations can represent other battlefield operating systems, integrating a candidate system's capabilities so that interoperability issues can be assessed. Additionally, virtual simulations can provide a method for assessing interoperability issues with personnel operating associated battlefield systems within doctrinal guidelines.

Some M&S was planned into the Javelin OT&E test design. A Model-Test-Model (MTM) process conducted on the Javelin program successfully correlated live OT&E test data with models generated on Janus. Three scenarios with six missions each were conducted on the Javelin model, including offensive and defensive Javelin employments. The resulting data provided Javelin employment assessments in an operational environment. OT&E test scenarios were changed to incorporate the MTM recommendations. Integrating MTM efforts into future OT&E test designs can improve test scenarios and environments, and therefore, enhance operational assessments. (IR MTH, 1993)

c. *AH-64D Longbow Apache*

During comparative performance assessment between the AH-64D and the AH-64A, threat forces were realistically deployed and represented a mid-intensity conflict. (Stanfield, March 1997) However, the AH-64D Longbow Apache OT&E test design had threat realism shortfalls for high intensity conflicts. After the IOT&E comparative assessement, further test designs did not replicate many of the threat weapons expected in a combat environment. Planned threat air defenses were under-represented and lacked realistic electronic jamming capabilities. Additionally, threat air assets were under-represented and excluded from many planned test scenarios.

M&S can provide methods for addressing threat realism shortfalls in live OT&E test designs. Constructive simulations can replicate the full range of threat capabilities expected in a combat environment. Additionally, virtual simulations, incorporating Semi-automated Forces (SAFOR), can provide a means to include man-in-the-loop threat forces employed by soldiers using doctrinally correct threat tactics.

M&S applications were used in the Longbow Apache OT&E test design process. TEXCOM validated the scenarios for the test plan using Janus constructive simulations. In addition, the Longbow Hellfire missile was examined in various electronic warfare counter-measure situations using a hardware-in-the-loop simulation. These pretest simulations were used to establish Hellfire probability of hit (Ph) and probability of kill (Pk) for casualty assessments. The success of M&S integration in the Longbow Apache operational test indicates that M&S application can improve the test design process.

d. *Test Design Summary*

In many operational tests, the live test represents only a small part of the actual combat environment for the weapon system. As a result, the data collected and the test evaluations represent only a part of the operational spectrum. Data for evaluation in larger operational assessments, beyond the live test design, must be extrapolated to address the weapon system's combat effectiveness and suitability. As the scope of live testing is reduced, increases in data extrapolation reduce evaluation validity.

M&S integration into the OT&E test design appears to provide an opportunity for addressing areas that are beyond the scope of the planned live test. M&S applications, including MTM, constructive simulations, and virtual simulations can enhance the OT&E test design process. Candidate systems in a constructive or integrated simulation can be portrayed at every echelon in the Army structure, under varying physical and threat environments, and interoperating with other battlefield and logistics systems.

2. Resource Constraints

A declining DoD budget adds pressure on PMs and testers to limit the scope of operational testing. Under funding and limited resources contribute to reduced realism in OT&E. Resource constraints had a serious negative impact on the MlA2 and Javelin tests.

a. *M1A2 Main Battle Tank and Javelin Missile*

Due to lack of congressional funding and limited test ranges, the M1A2 and the Javelin were tested at the small unit level. The horizontal interoperability and vertical impact on higher echelon units could not be ascertained by the OT&E tests conducted. Resource constraints limited the inclusion of associated battlefield operating systems and support elements that would normally be deployed in a combat environment. Interoperability evaluation could not be addressed from test data collected. Realism in live testing goes beyond the small unit. For example, recovering and evacuating an M1A2 tank from the battlefield to the corps level general support maintenance unit requires significant recovery and transportation assets as well as multi-echelon coordination. M1A2 OT&E test resource constraints did not allow this scenario to be replicated beyond the participating battalion's organic recovery capabilities. The Javelin experienced similar problems in resupply of missiles to forward troops during high threat combat environments. In the Javelin Live test, the General Support unit was not utilized.

Interoperability with other systems, beyond the scope of live testing, can be partially assessed through M&S. For example, the TRAC White Sands Missile Range (WSMR) simulations addressed M1A2 capabilities in various environments and scenarios beyond the scope of live testing. Using simulation applications, the M1A2 could be portrayed interoperating with close air support, artillery and any other battlefield operating system including critical logistics support activities. The capability to fully replicate interoperability, both horizontal and vertical, is currently outside the resource-constrained OT&E environment.

Resource constraints have a considerable impact on the planning of live tests. However, M&S has application in addressing the OT&E test shortfall created by resource constraints. The marginal cost of M&S generated operational events is extremely low compared with those same events conducted in the live environment. An example of the wide disparity between live and M&S resource requirements involves M1A1 main battle tank prototypes. In 1984, evaluations of possible improvements on the M1A1 Abrams tank were carried out by using real tanks in a live environment. The effort took 24 months and cost $40 million. A later effort in 1986 used a modified aircraft dome simulator, took only six months and cost $1 million. In 1992, using Distributred Interactive Simulation (DIS), four variations of the M1A1 Abrams were operated against potential threats, taking only three months and costing $640, 000. (Berry, 1992)

b. *Resource Constraint Summary*

Resource limitations impact realism and reduce the scope of the operational testing. Reduced realism in operational testing results in less quantitative and more qualitative evaluations of the candidate weapon system. Reduced scope in operational testing increases data extrapolation for larger force-on-force evaluations.

Virtual and constructive simulations can enhance OT&E tests that have been negatively affected by resource constraints. Virtual simulation can provide methods for representing threat and friendly force capabilities that are too expensive or impractical to replicate in a live operational test environment. Constructive simulations can provide a means to assess portions of the operational spectrum outside the scope of live testing.

3. Safety and Environmental Concerns

Safety and environmental impacts of new technology and hazardous complex compounds adversely affects the successful creation of a realistic combat environment for operational testing. Peacetime requirements often limit the amount and type of testing that can be accomplished, unlike the combat environment where safety and environmental side effects are not so important. Safety and environmental issues affected the M1A2, Javelin, and Longbow Apache OT&E tests.

a. *Range Limitations*

A common problem in conducting live operational tests are the peqacetime range limitations. Range limitations affected the operational employment of the M1A2, Javelin, and Longbow Apache systems during OT&E. The ranges used had well marked firing limits and oriented the crews toward target positions. Lasers, for all but the Javelin Missile, were restricted to controlled maneuver and air spaces. Controlled maneuver and air spaces did not provide representative maneuver space or engagement ranges. Environmental concerns eliminated operational firing of depleted uranium M1A2 main gun rounds due to radiation hazards.

Both constructive and virtual simulation applications provide environments that are not affected by these types of safety and environmental range limitations. As a result, tests generated through M&S can avoid such biased factors.

b. *Crew Safety Requirements*

Both PM and TEC test officers strictly followed peacetime crew rest requirements for helicopter pilots, tank crews, and ground soldiers. These crew rest requirements are not representative of typical combat crew duty cycles, which are not constrained to peacetime training restrictions. Additionally, during OT&E the weapons systems were not tested to the normal operational readiness factors associated with combat operations.

In a protected simulation environment, where there are no actual threats to the safety of soldiers and where safety considerations are nearly nonexistent, M&S applications can be used to assess the impact of extended combat operations on aircraft and ground crews. For example, relatively close air-to-air combat involving more than the safety constrained two-on-two force ratios are not probable in an operational environment. Virtual or constructive simulations provide a means to address issues involving more than two-on-two force ratios. Crew safety concerns make simulation a viable and practical method for obtaining this type of operational data.

c. *Safety and Environmental Concerns Summary*

Safety and environmental concerns negatively impact on the ability to assess the operational effectiveness and suitability of candidate weapon systems. Integrating M&S into the

OT&E process provides a means for assessing issues in an environment that is not constrained by safety and environmental concerns. Virtual and constructive simulation applications can be integrated into operational tests that cannot be safely or environmentally conducted in a live operational environment. Additionally, when test events are limited in number due to safety or environmental concerns, model-test-model (MTM) can provide a method to extend data and enhance operational evaluations.

4. Test Data Reliability and Validity

The myriad of variables present in a live test environment impact on data reliability and validity. One of the most common concerns in obtaining reliable and valid test data is how well test personnel represent typical users at the operational level. The M1A2 and Longbow Apache experienced data reliability and validity concerns due to crew experience levels that were above typical tactical unit proficiency levels. Experience level of test crews centers on two issues: 1)Pre-training of test personnel for the specific OT&E event, 2) operational expereince of test participants. OT&E personnel at TEC indicated that the M1A2 and Longbow Apache OT&E had problems associated with *atypical* test participants. For both weapon systens, OT&E test participants were tasked from tactical units for the test duration.

a. *M1A2 Test*

Training and familiarization of the M1A2 test crews were conducted on the same ranges and maneuver areas as the OT&E test trials. Decisions, response times, and accuracy of weapons firing were considered superior to what could be expected in a combat environment because of familiarity with the test ranges. Many of the battle position were pre-designated and maneuver was artificially controlled to meet range requirements. Pre-testing training and range control procedures contribute in making M1A2 test participants *atypically* qualified.

b. *AH-64D Apache*

Because of the complex nature of the AH-64D, the operators were selected from the same operational unit, A/2-229th. (Stanfield, March 1997) Using all of the test participants from an single unit could bias test data. For example, of the sixteen pilots for the operational test, the majority were senior chief warrant officers (CW3 or CW4) who have worked together over long periods of time. Their pilot skills were considered to be *atypically* high when compared with less experienced pilots prevalent in the operational units. Additionally, ranges at Hunter Liggett required the use of common battle positions for testing. Again, pre-test training and familiarization with range procedures will enhance the crews ability to quickly and effectively engage targets from designated battle positions.

The Distributive Interactive Simulation (DIS) network provides an opportunity to address the *atypical* crew problem. Test participants selected over a wide geographic area can be linked together through DIS and participate in OT&E testing without leaving their home station. The tendency to select *atypical* users at home station would be reduced because participants remain anonymous and are not representing the unit as individuals. The same techniques could be used to train test participants without familiarizing them with the limited test ranges and maneuver areas used for live test events. Data collected in this manner would enhance reliability and validity, thus improving the evaluation.

c. *Test Data Reliability and Validity Summary*

Data reliability and validity are affected by the OT&E test scope, realism achieved, and the degree to which test participants represent typical users. Operational assessments of combat effectiveness and suitability are directly affected by data validity and reliability. Integrating M&S into the OT&E process through the use of model-test-model (MTM), virtual, constructive, and Distributed Interactive Simulations (DIS) enhances data reliability and validity, and therefore, weapon system evaluations become more accurate.

The uniform quality of M&S-generated data appears to enhance the reliability and validity of OT&E data. M&S-generated data are less susceptible to bias because the variables are controlled by design. Additionally, testing can be replicated for reliability and validity. Fully verified, validated and accredited M&S applications specifically designed for data collection produce uniform quality data which should enhance the evaluation process.

D. SUMMARY

Integration of advanced M&S techniques, technologies, and applications into OT&E can provide a means of addressing operational test issues beyond the scope of resource-constrained live testing. M&S provides a vehicle for addressing critical issues that are impossible or impractical to represent in a live environment. Operational realism and combat stress may be enhanced through M&S application.

Integrating M&S does not replace or eliminate live operational testing, but rather augments and focuses live testing. The adage "you don't use M&S to identify what is exactly right, you use it to eliminate what is exactly wrong " applies to OT&E test design. Integrating

M&S into OT&E design reduces variability by examining critical issues across the operational spectrum replicated on a simulation.

VI . CONCLUSIONS AND RECOMMENDATIONS

A. OVERVIEW

The OT&E process has a major impact on a weapon systems' critical acquisition decisions. The importance of OT&E in the acquisition process is underscored by Congressional interest in the OT&E process and it's results. OT&E assessments are reported directly to Congress from independent OT&E sources. From early operational assessments through the formal operational evaluation, the insights to a weapon systems' characteristics are based on operational tests. The accuracy of OT&E in predicting how weapon systems will operate in a combat environment directly affects future combat implementation, and more importantly, the survival of the combat troops who depend upon those weapon systems.

M&S integration into the OT&E process has traditionally been limited. In the past, M&S maturity was limited to physical models and mathematical simulation. Advancements in software, hardware, and linked communications networks have resulted in explosive M&S growth and maturity. However, the OT&E community is slow to integrate advanced M&S due to the desire to protect their independent status and the perceived negative connotation associated with anything "simulated" in a live test environment.

This thesis focused on the potential opportunities to integrate M&S concepts and applications into the Army OT&E process. Recurring OT&E concerns were examined and possible M&S based enhancements and solutions were identified. Increased M&S integration in the weapons testing will enhance the OT&E process.

B. GENERAL CONCLUSIONS

Realistic operational combat effects on personnel and equipment cannot be wholly replicated through constructive simulation or virtual simulation in operational testing. Live testing in a replicated combat environment provides the most realistic operational test, however, it is the most expensive OT&E method. A coordinated approach to operational testing, integrating live tests with models and simulation M&S, provides a realistic environment for effective OT&E. M&S cannot, and should not be used in place of necessary OT&E live testing. However, M&S applications offer methods of augmenting and enhancing the OT&E process that merit consideration.

The tremendous costs associated with conducting comprehensive live testing will limit its use in the budget restrained future. Army budgets are projected to continue the present downward trend, which will not improve the prospects for expanding OT&E live testing. The requirement to create holistic, representative operational environments conflicts with the realities of the reduced current budget and projected defense funding authorizations. M&S applications can bridge the funding gap, assisting both the PM and operational testers in providing good equipment for the user.

Interviews and research indicate there are significant problems and concerns associated with the Army OT&E process. Some believe that failures during OT&E are management failures, rather than learning opportunities. Many focus on the inability of limited OT&E to adequately assess the combat effectiveness and suitability of weapon systems, as required by law. Whatever the reason for limited test, it can lead to the fielding of weapon systems whose operational effectiveness and suitability have not been fully demonstrated. Inadequate operational testing tends to yield more favorable assessments than are likely to be found when the systems are employed in combat.

The integration of M&S can provide some solutions to recurring OT&E problems and issues. Integrating M&S into the OT&E process can provide valuable insights into the operational environment beyond the scope of a resource constrained OT&E process. However, M&S cannot fully represent the personnel stresses associated with combat environments. Additionally, M&S cannot replicate the infinite number of variables present in live environments.

C. SPECIFIC CONCLUSIONS

1. Test Design

Interviews with PM and OT&E professionals indicated that during OT&E it is impossible or impractical to portray the full range of force structures. Demonstrating a weapon system's integration with friendly forces and interoperation with potential threat capabilities is difficult for even the most basic system. This is largely due to the fact that current methods for planning OT&E and validating that plan are not efficient or effective.

Integrating M&S into the OT&E test design process can assist the PM and test planners in addressing the problems and issues associated with test design. Constructive simulations can provide a means of examining the candidate weapon system's entire operational spectrum. Force structures, interoperating systems, and threat capabilities can be represented in the constructive environment. Integrating live test events with constructive simulations, such as Model-Test-Model applications, can identify scenarios and environments required to address critical testing issues.

2. Resource Constraints

Resource constraints limit the scope of live OT&E testing. The operational test often shrinks as resources are constrained. Resource constraints limit the degree to which realism is replicated in a live test environment. These constraints increase the risk that the OT&E will neither accurately nor adequately address the combat environment that potential weapon systems might experience.

Integrating M&S into OT&E testing can reduce the impact created by resource constraints. Constructive and virtual simulations can provide methods to address operational issues beyond the scope of resource constrained live testing. M&S applications are more cost effective than live test events and, therefore, are less susceptible to the negative effects resulting from resource constraints. Virtual simulations accommodate actual users in an unconstrained environment. This provides critical user responses in environments with realistic threat capabilities, interoperability with other battlefield operating systems, and force structures impossible to replicate in a live environment.

3. Safety and Environmental Concerns

In today's testing environment, safety and environmental issues increasingly limit the ability to fully consider critical issues in a live OT&E. New technology advancements including lasers, depleted uranium projectiles, and other potentially hazardous systems cannot be addressed in an unrestricted, live operational test. Systems that produce environmentally hazardous by-products are restricted to very controlled scenarios, not representative of a combat environment. Additionally, peacetime safety requirements, significantly more restrictive than those expected in a combat environment, negatively impact OT&E assessments.

Integrating M&S into the OT&E process can provide solutions for data collection when scenarios are restricted by safety or environmental concerns. M&S can provide a means to address critical issues that are too hazardous or environmentally polluting to conduct in a live test. In extreme situations, M&S may provide the only OT&E data obtainable for OT&E evaluation.

4. Data Reliability and Validity

Limited operational testing creates data reliability and validity problems and issues. Data collected from limited OT&E must be extrapolated to the operational spectrum not addressed within the scope of live OT&E. As the OT&E test scope becomes smaller and more constrained, data reliability and validity risks increase. The myriad of variables present in a live OT&E environment invites questionable interpretation of the results. False causes may be assigned to some undesirable events that eliminate, obscure, or reduce the certainty of the failure.

OT&E test participants are often not representative of the typical operational user. Data reliability and validly suffer when "golden crews" (personnel who are *atypically* high in aptitude and attitude) are used to represent the "typical" user. Training test participants on the same ranges and maneuver areas used for OT&E test trials creates unrealistic responses. This familiarity improves response times, anticipation, and weapon accuracy.

Integrating M&S into the OT&E process can assist in addressing data reliability and validity related problems and issues. M&S applications can provide a means to augment data required for quantitative evaluation. Data generated on M&S applications have controlled variables, virtually eliminating the opportunity for event interpretation and manipulation. DIS can provide an effective means for addressing the "golden crew " problem. Data collection and test participant training via DIS preserve the actions, reactions, and decisions of representative operational users.

D. RECOMMENDATIONS

The following recommendations, based on weapon system analysis, should enable M&S to enhance and improve the Army OT&E process:

1. The Army should continue to expand existing M&S efforts in requirements generation, data augmentation, and OT&E testing. Cooperative M&S efforts between OPTEC and TRADOC will enhance the OT&E process through early and accurate critical issue identification and test design validation. As a result, OT&E test data will be improved and combat effectiveness and suitability assessments will be more accurate.

2. M&S applications that have the fidelity to integrate candidate system capabilities and parameters for OT&E should be developed. The M&S applications developed should portray existing threat and friendly force structures from small unit through theater level environments. These applications should include constructive and virtual simulations that can examine the impacts on threat capability, battlefield interoperability, and logistics supportability issues. Accurate simulations provide methods for examining the operational spectrum beyond the live test scope. Extrapolation of live test data via M&S can enhance data and evaluation accuracy.

3. Verification, Validation and Accreditation (VV&A) requirements for previously validated applications should be limited to the candidate systems' capabilities and parameters. The VV&A process for M&S applications is time consuming and expensive. M&S applications with pre-approved VV&A accreditation could enhance M&S integration into the OT&E process.

4. Equipment simulators at user locations should be linked through DIS. Virtual simulations, linked through the DIS network, would integrate a wide variety of typical users for operational assessments. Test participant training at home station through DIS could improve OT&E data validity during live test trials.

E. AREAS FOR FURTHER RESEARCH

Further research is recommended in the following areas:

1. Research should be conducted to determine the differences between test participant actions, reactions, and decisions in live versus simulated environments. The results of this research should help establish the degree to which M&S generated reaction and decision data correlate with live operational testing.

2. The integration of high fidelity M&S applications should be analyzed. Candidate system employment via high fidelity simulations could provide effectiveness and suitability assessments while varying doctrine and tactics. Additionally, threat forces controlled through high fidelity simulations could provide probable threat adjustments to the employment of candidate weapon systems.

3. The compatibility of current and future weapon systems training simulation devices with DIS and other M&S architectures should be investigated. Dual use of training simulation devices for training and OT&E testing via virtual and distributed simulations could enhance the M&S integration into the OT&E process.

APPENDIX

ADS- Advanced Distributed Simulations
AMC- Army Material Command
AMIP- Army Model Improvement Program
AMSAA- Army Material Systems Analysis Activity
AMSMO- Army Modeling and Simulation Management Office
AR- Army Regulation

BDS- Battlefield Distributed Simulation
BDS-D- Battlefield Distributed Simulation-Developmental

C&C- Command and Control
C4I- Command, Control, Communications, Computers, and Intelligence
CEP- Concept Evaluation Program
CITV- Commander's Independent Thermal Viewer
COI- Critical Operational Issue
CW3- Chief Warrant Officer - 3
CW4- Chief Warrant Officer - 4

DA PAM- Department of the Army Pamphlet
DARPA- Defense Advanced Research Project Agency
DIS- Distributed Interactive Simulation
DMSO- Defense Modeling and Simulation Office
DoD- Department of Defense
DOT&E- Director of Operational Test and Evaluation
DSB- Defense Science Board
DSI- Defense Simulation Internet
DT&E- Developmental Test and Evaluation

EMD- Engineering and Manufacturing Development
EUTE- Early User Test and Evaluation

FDTE- Force Development Testing and Experimentation
FFRDC- Federally Funded Research and Development Center
FOTE- Follow-on Operational Test and Evaluation

HW/SWIL- Hardware/Software-in-the-loop

IOTE- Initial Operational Test and Evaluation
IPPD- Integrated Product and Process Development
IVIS- Intervehicular Information System

JT&E- Joint Test and Evaluation

LAM- Louisiana Maneuvers
LRIP- Low Rate Initial Production

M&S- Modeling and Simulation
MAIS- Major Automated Information systems
MDAPS- Major Defense Acquisition Programs
MNS- Mission Needs Statement
MOE- Measure of Effectiveness
MOO- Measures of Outcome
MOP- Measure of Performance
MOS- Military Occupational Skill
MTM- Model-Test-Model

OEC- Operational Evaluation Command
OPEVAL- Operational Evaluation
OPTEC- Operational Test and Evaluation Command
ORD- Operational Requirements Document
OT&E- Operational Test and Evaluation

PDRR- Program Definition and Risk Reduction
PDU- Protocol Data Unit
Ph- Probability of Hit
Pk- Probability of Kill
PM- Program Manager
PPBS- Planning, Programming, and Budgeting

R&D- Research and Development

SAFOR- Semi-automated Forces
SIMNET- Simulation Network
SIMTECH- Simulation Technology Program
STRICOM- Simulation, Training and Instrumentation Command

T&E- Test and Evaluation
TEC- TEXCOM Experimentation Center
TEMP- Test and Evaluation Master Plan
TEXCOM- Test and Experimentation Command
TMDE- Test Measurement Diagnostic Equipment
TRAC- Training and Doctrine Command Analysis Center
TRADOC- Training and Doctrine Command

VV&A- Verification, Validation, and Accreditation

WBS- Work Breakdown Structure
WSMR- White Sands Missile Range

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